Beyond the Bioeconomy: The New Paradigm for Carbon Sourcing and Synthesis for the New Carbon Economy

David Babson, PhD | ARPA-E Program Director
david.babson@hq.doe.gov

Reactive Carbon Capture Workshop
February 1, 2022

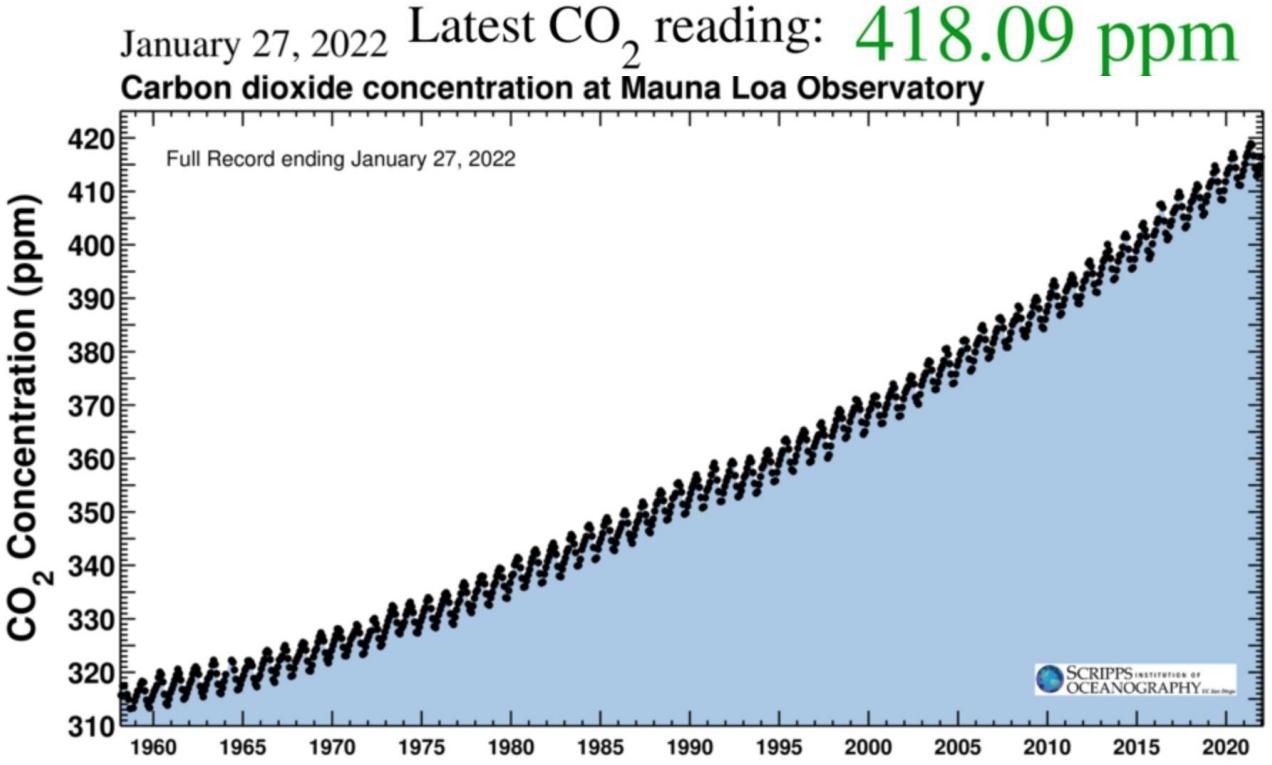
arpa·e

THE NEW CARBON ECONOMY

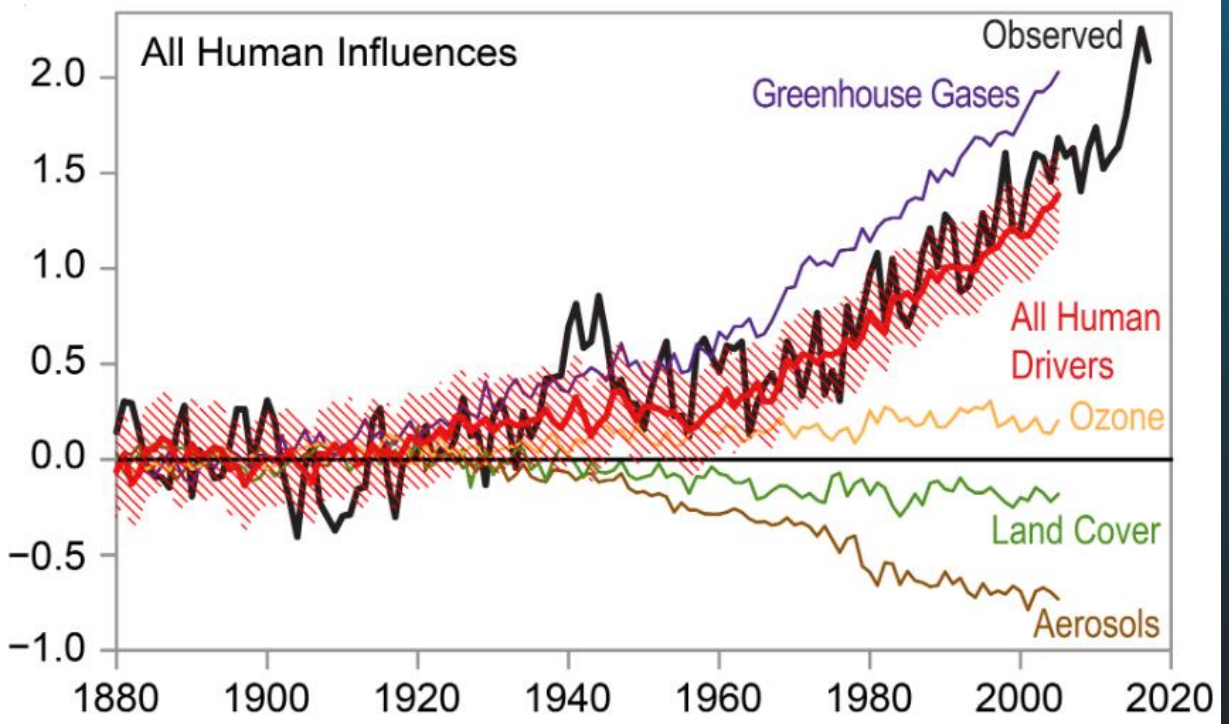
arpa·e
CHANGING WHAT'S POSSIBLE

It’s real, we know what’s causing it, and we have known for a long time

It is Climate Change



The Keeling Curve



Temperature correlation to human influences

Fourth National Climate Assessment. Volume II. USGCRP. November 2018

arpa·e
CHANGING WHAT'S POSSIBLE

A carbon-conscious economy is not a *low-carbon economy* as much as it will be a *renewable "new" carbon economy*

The low carbon economy incentivizes carbon reduction

The new carbon economy will incentivize carbon optimization

The bioeconomy has a *changing* role to play in this economic future

arpa·e
CHANGING WHAT'S POSSIBLE

The Bioeconomy Concept

(envisioned the context that *reducing* emissions is enough)

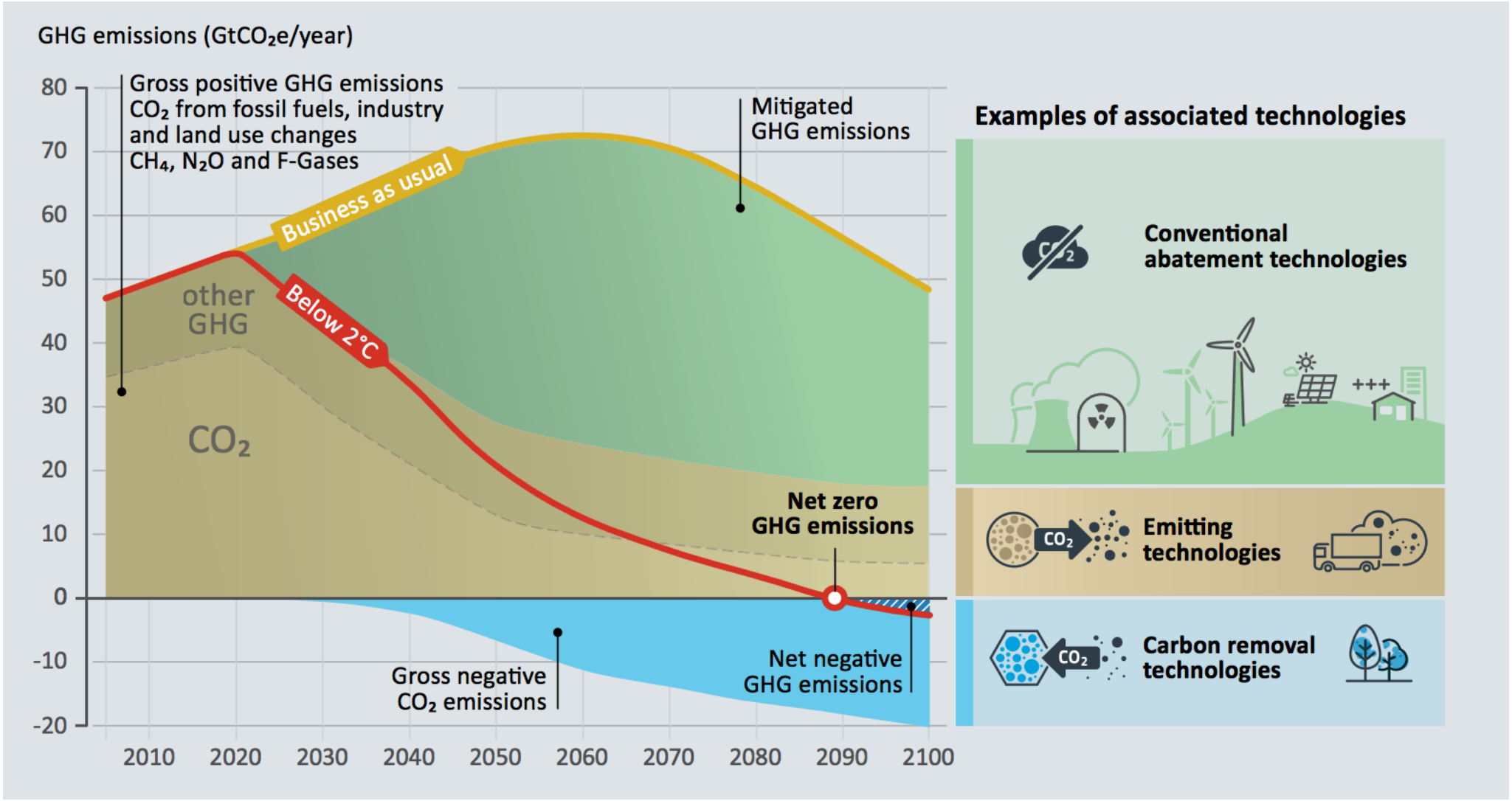
Feedstock → Conversion → Products

- Revenue, economic, and broad spectrum job growth
- Advanced technologies and manufacturing
- Reduced emission, environmental sustainability, and climate mitigation
- Rural development, and investments and new infrastructure

ACUTE CHALLENGES REQUIRE TRANSFORMATIVE NEW TECHNOLOGIES FOR *NEW* CARBON SOURCING AND SYNTHESIS

arpa·e
CHANGING WHAT'S POSSIBLE

All paths to 2° C go through zero

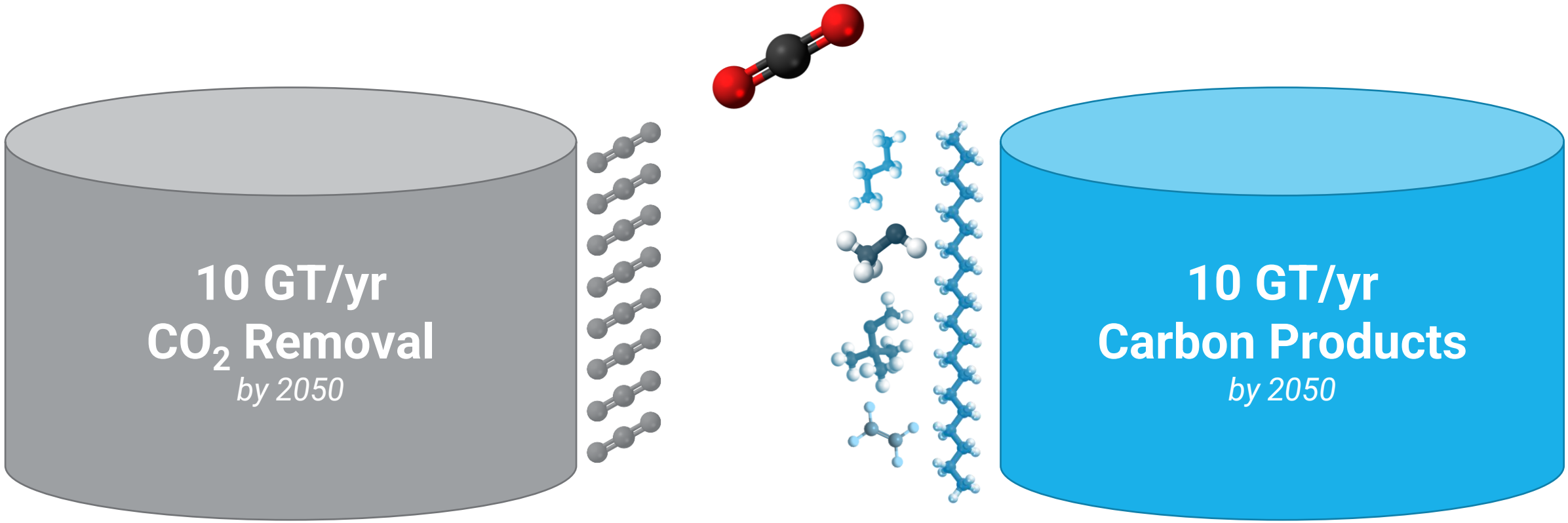


National Academy of Sciences. *Negative Emissions Technologies and Reliable Sequestration: A Research Agenda.* 2019. p. 3

arpa·e
CHANGING WHAT'S POSSIBLE

There are two *new carbon* buckets that need to be filled

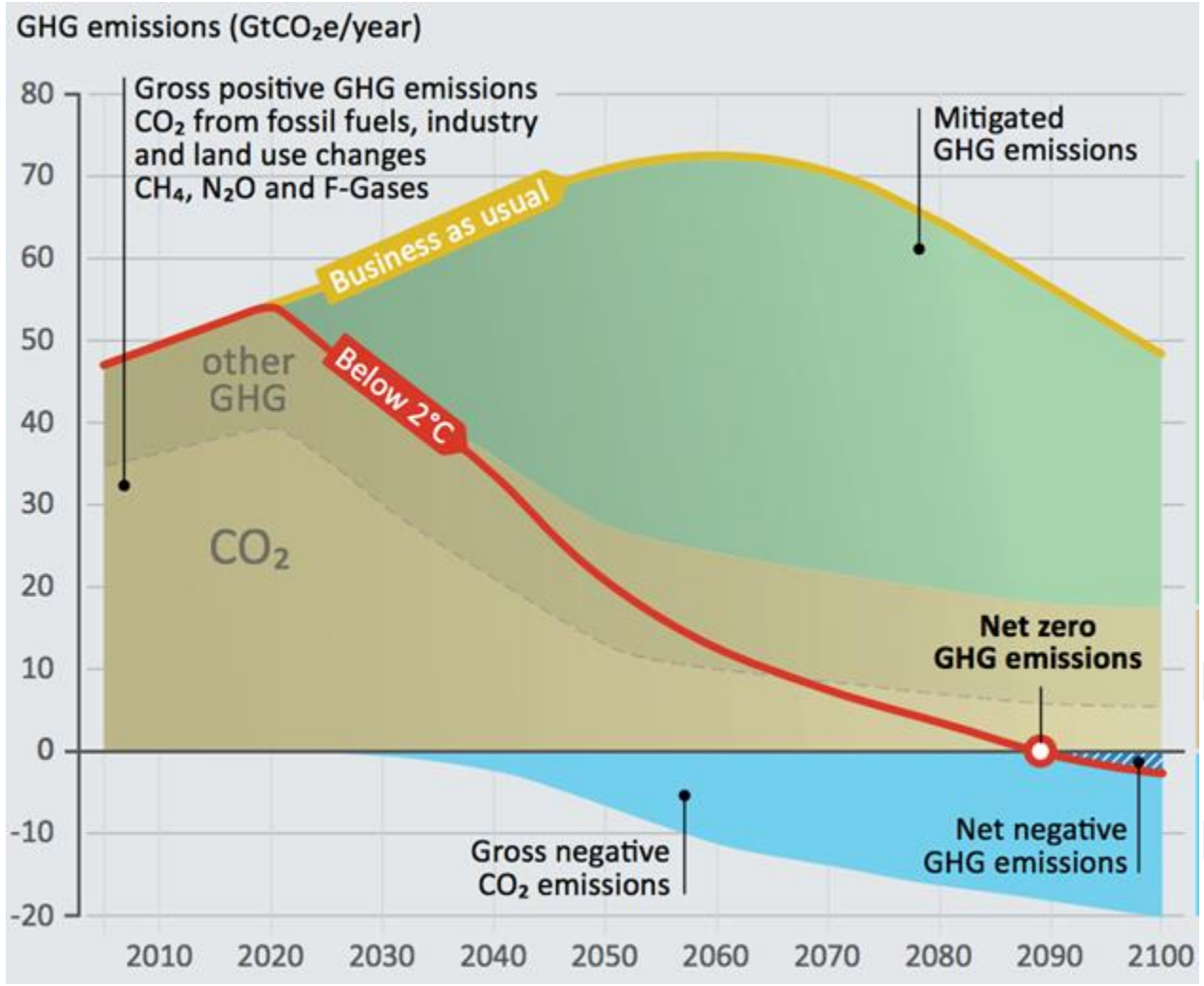
Where *new carbon* is sourced, where it is directed, or how it is used matters a lot.



Low energy ***High energy***

arpa·e
CHANGING WHAT'S POSSIBLE

How should we manage CO_2?



Getting to net negative emissions will require setting and achieving ambitious targets for *BOTH* carbon dioxide removal and utilization.

Carbon Neutral Products from Air & Water

Low-Cost*, Large-Scale, Near-Term CDR

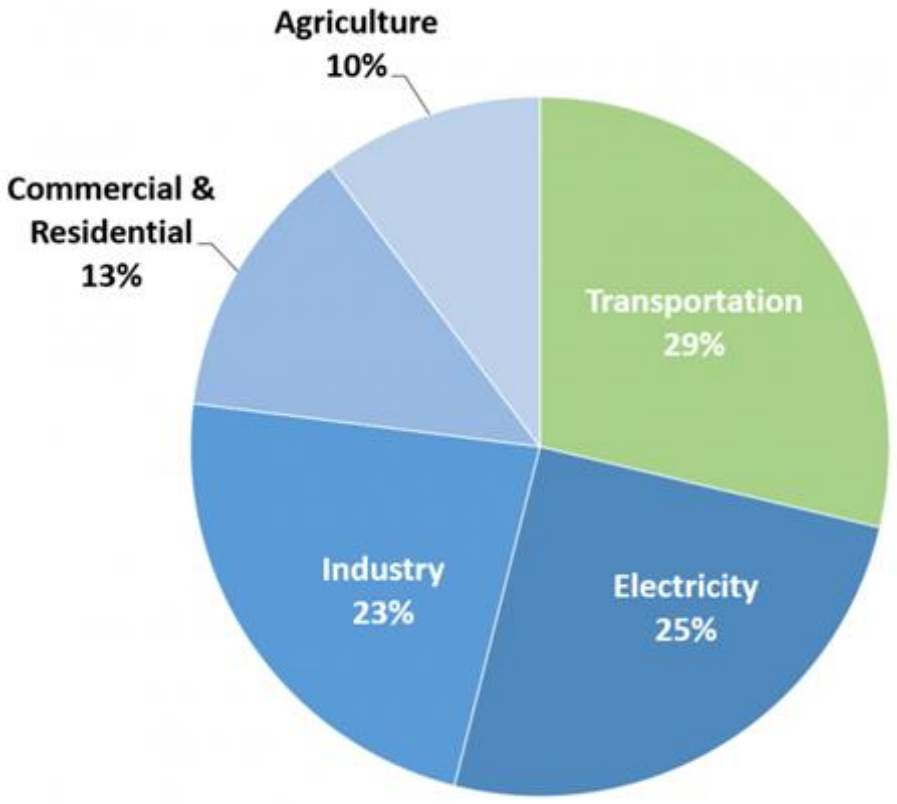
*including energy requirements

arpa·e CHANGING WHAT'S POSSIBLE

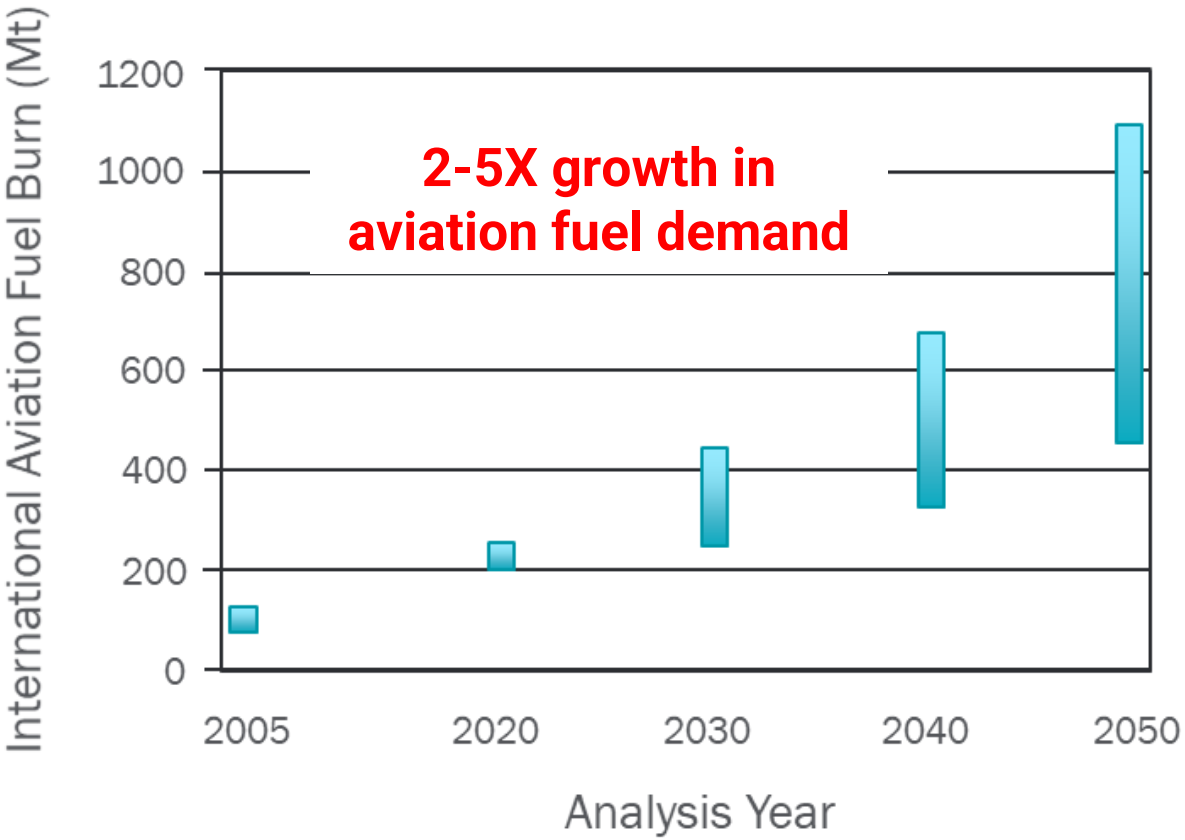
National Academy of Sciences. *Negative Emissions Technologies and Reliable Sequestration: A Research Agenda.* 2019. p. 3

Transportation sector GHG emissions are troublesome

~1/3 U.S. GHG emissions from transportation today



Even with light duty sector electrification, liquid fuel demand and associated GHG emissions will grow substantially

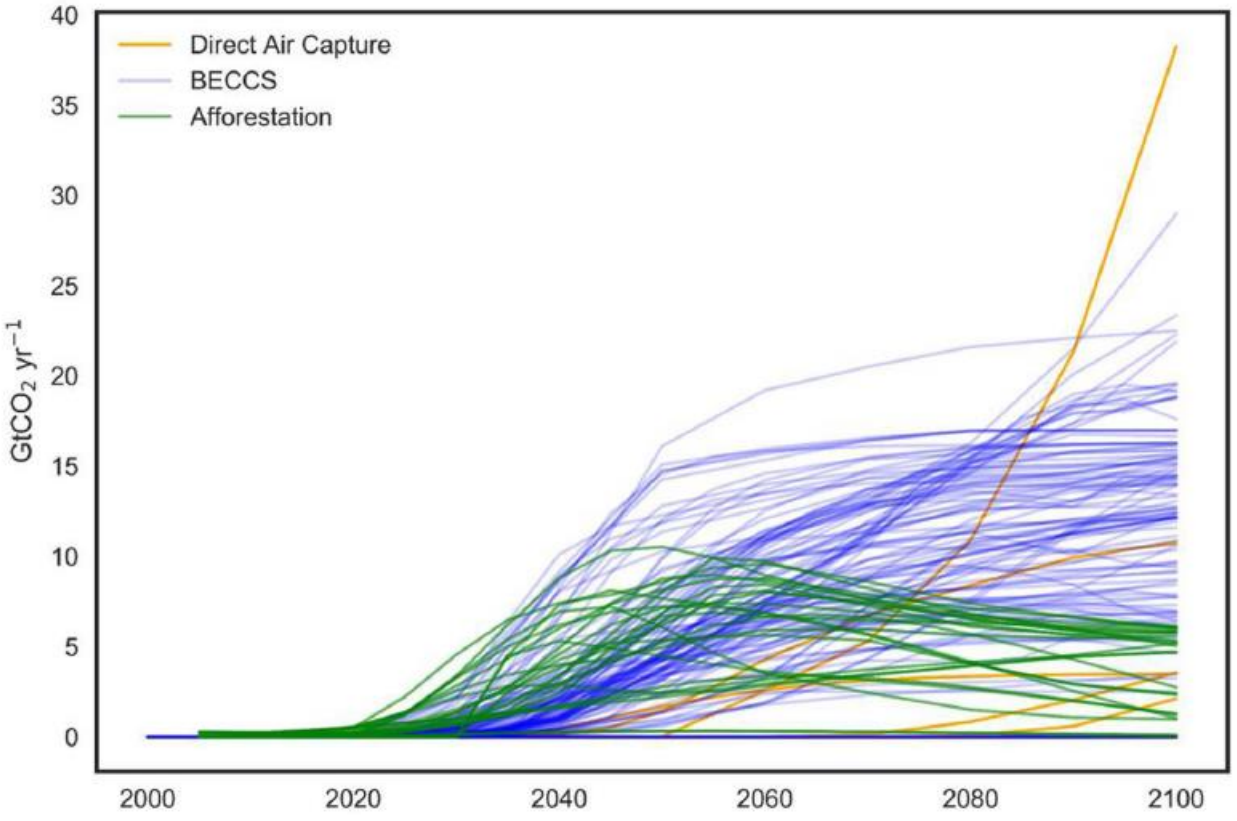


arpa·e
CHANGING WHAT'S POSSIBLE

1. EPA GHG Inventory, 2019
2. Adapted from ICAO, 2016: Range of Uncertainties Associated with Demand Forecast, 2005 to 2050
3. IRENA, Renewable Power Generation Costs in 2017

There will be new pulls on renewable biomass feedstocks

Comparison of NETs results from several different models reveal that virtually all rely primarily on BECCS to limit warming to 1.5◦C by 2100.



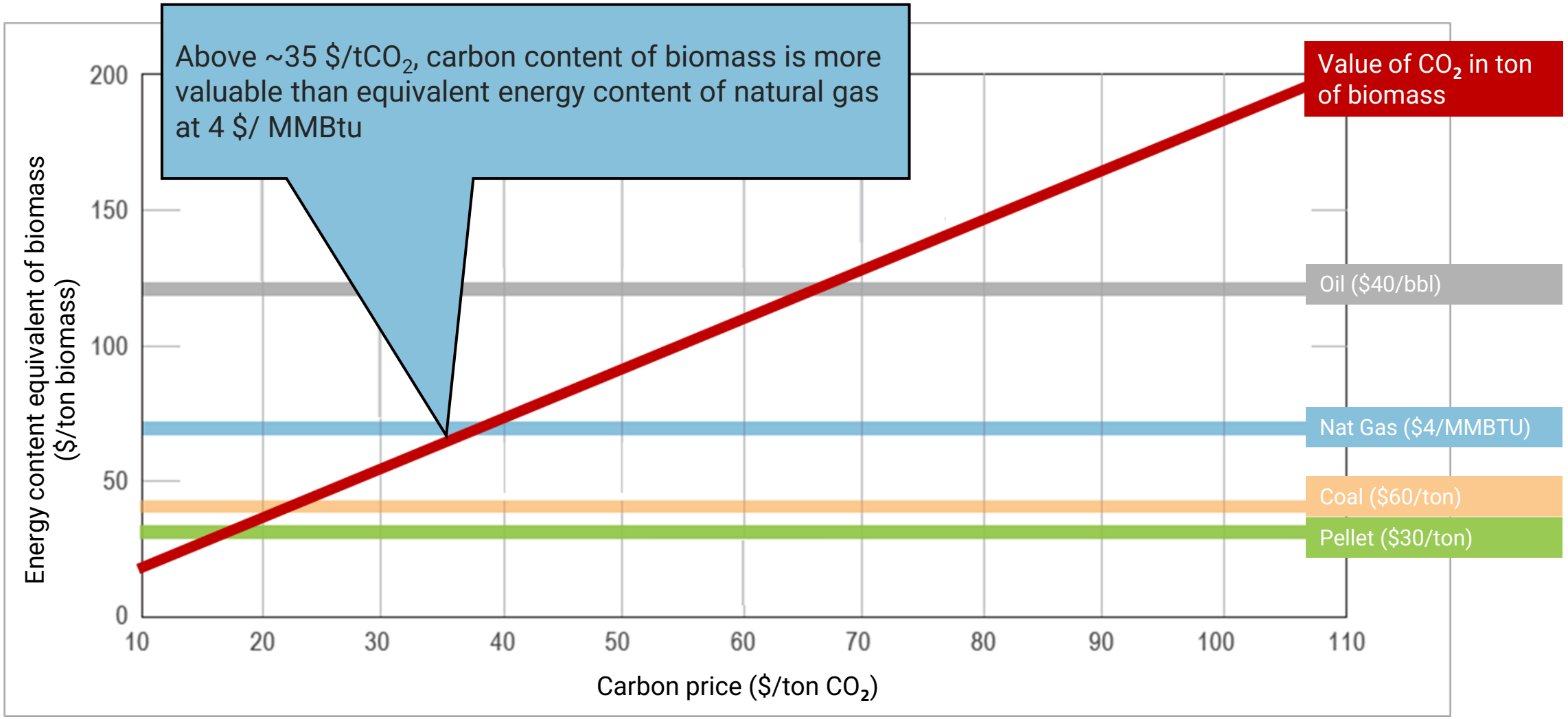
- Low-carbon grid stability
- Existing bioeconomy infrastructure

Data source: Huppmann et al. (2018).

arpa·e
CHANGING WHAT'S POSSIBLE

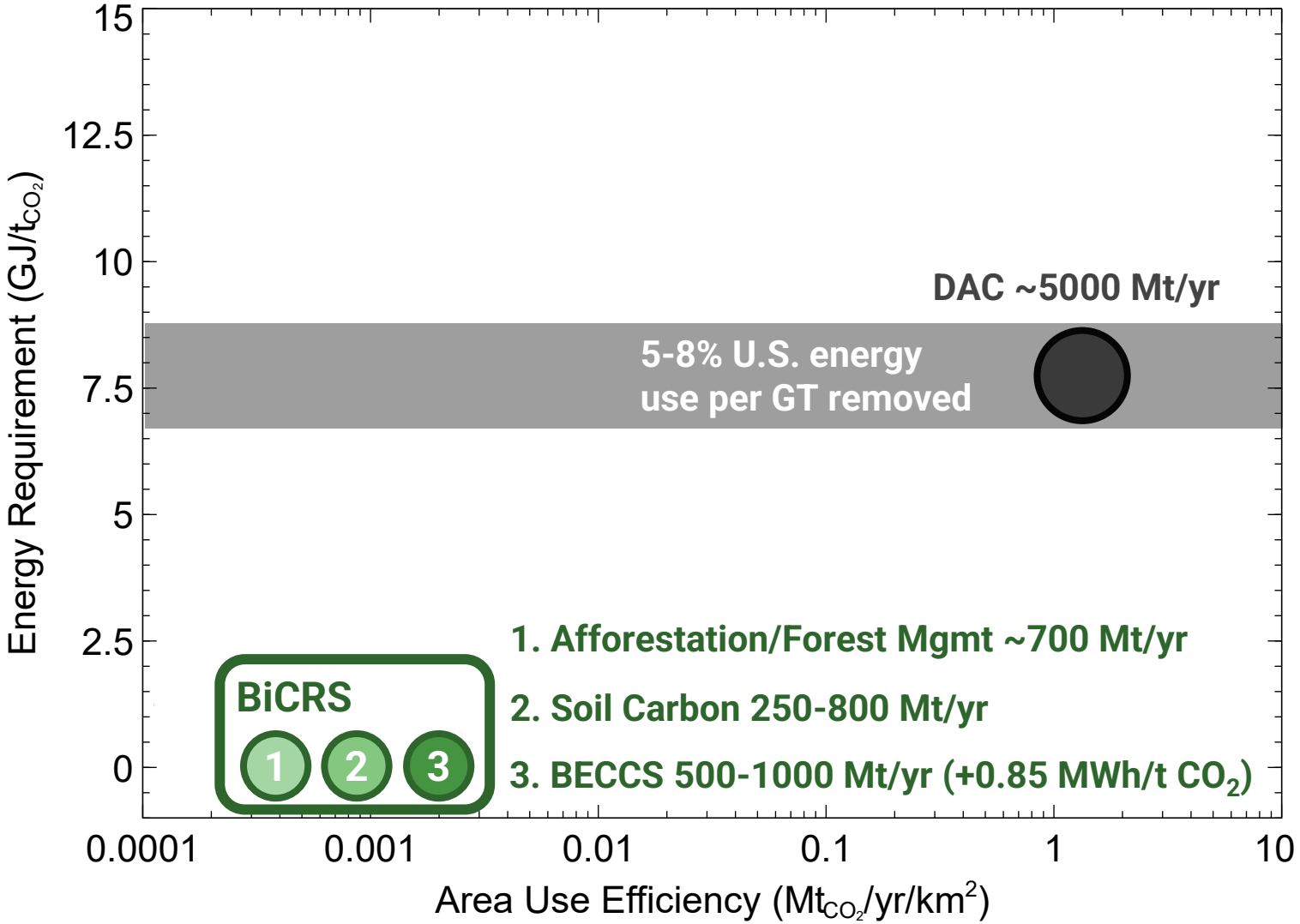
Carbon pricing redefines biomass from “energy crop” to “carbon removal crop"

Illustrative optimal uses of biomass for energy content vs carbon removal at different carbon prices



CO_2 removal via biomass alleviates CDR energy demand

...while delivering sustainable feedstocks for food, feed, fiber, and energy



Biomass Carbon Removal & Storage (BiCRS)

- Uses biomass to remove CO_2 from the atmosphere
- Stores that CO_2 underground or in long-lived products
- Does no damage to—and ideally promotes—food security, rural livelihoods, biodiversity conservation and other important values

>1 GT/yr removal @ <$50/t

Drivers for innovation – Carbon markets *can* promote both

Carbon / GHG Emissions Reductions

Land Sparing

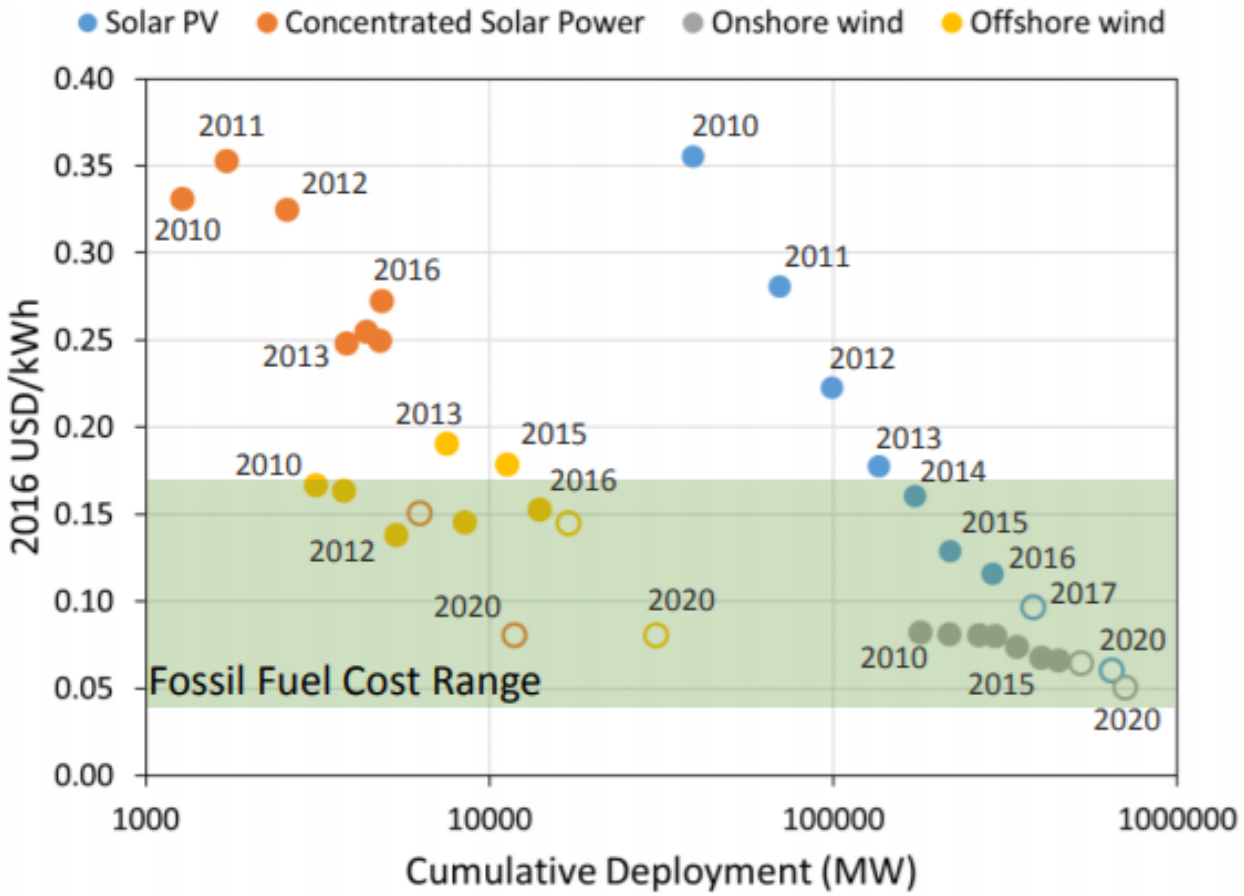
Our global economy needs to be structured in a way that incentivizes not only land and carbon 'neutrality', but promotes becoming both carbon and land negative.

arpa·e
CHANGING WHAT'S POSSIBLE

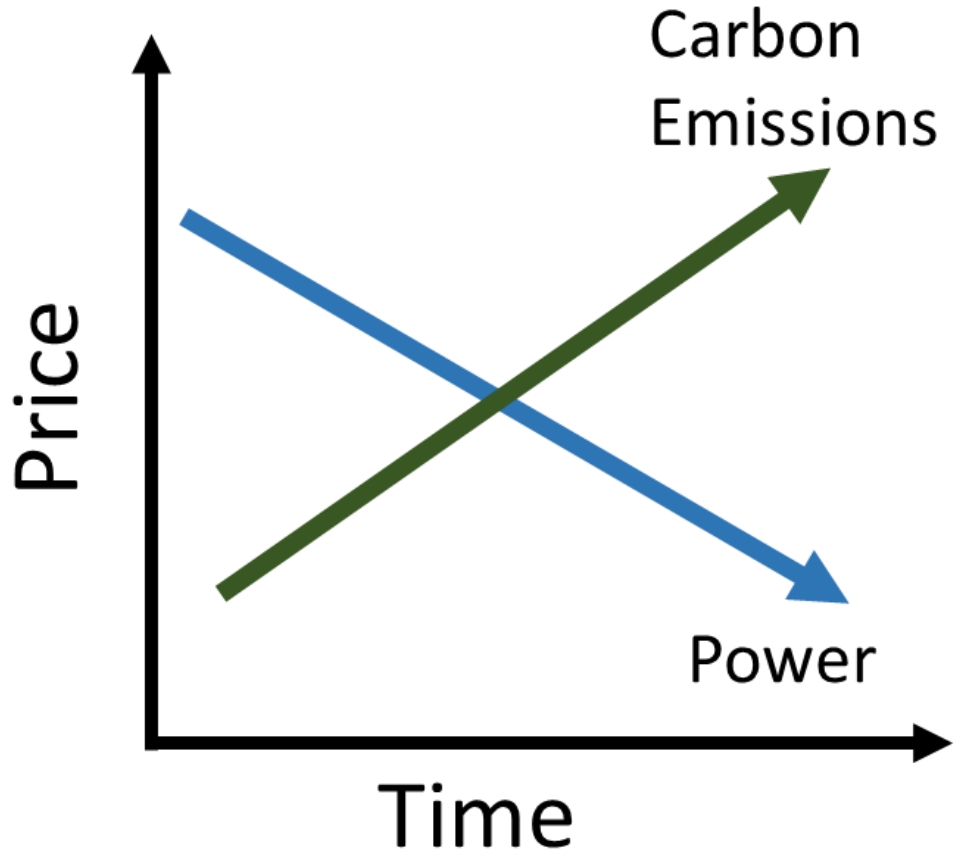
TECHNICAL HISTORY AND OPPORTUNITIES

Relevant trends in carbon and energy create new incentives in and opportunities for the new carbon economy

The price of low-carbon power is going down



The cost of wasting carbon is going up

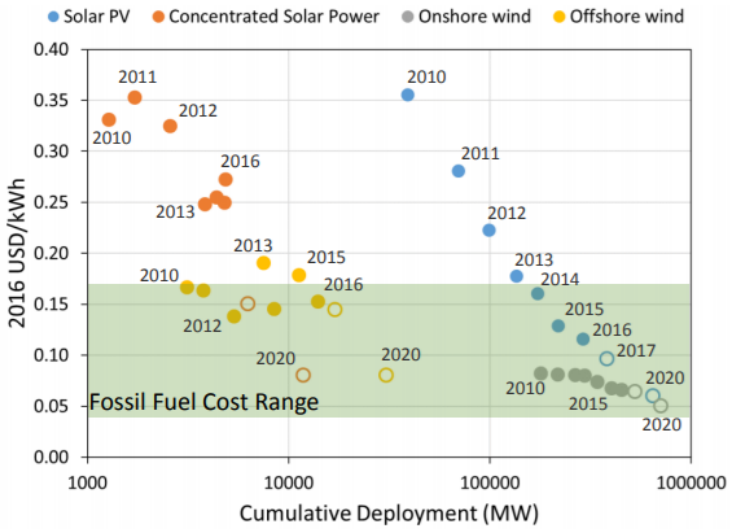


IRENA, Renewable Power Generation Costs in 2017

arpa·e
CHANGING WHAT'S POSSIBLE

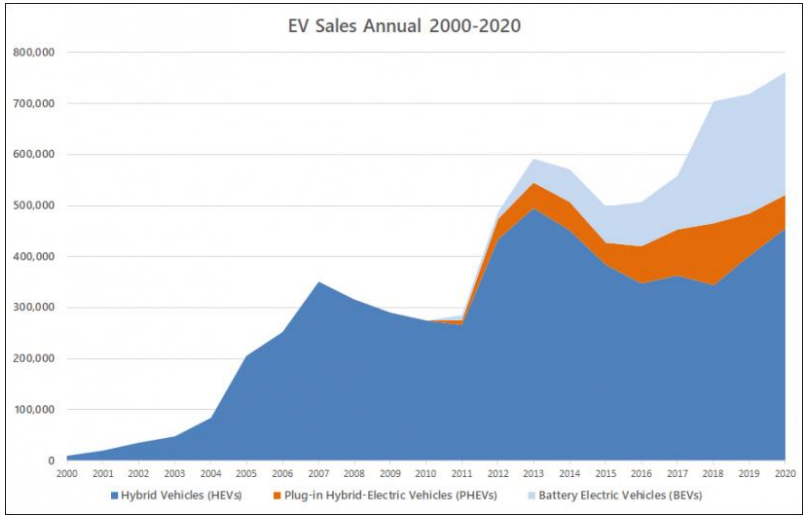
Changes in electricity and transportation indicate a need for new optimization strategies to promote carbon and land use efficiency

Low-carbon electricity decouples carbon intensity from energy intensity



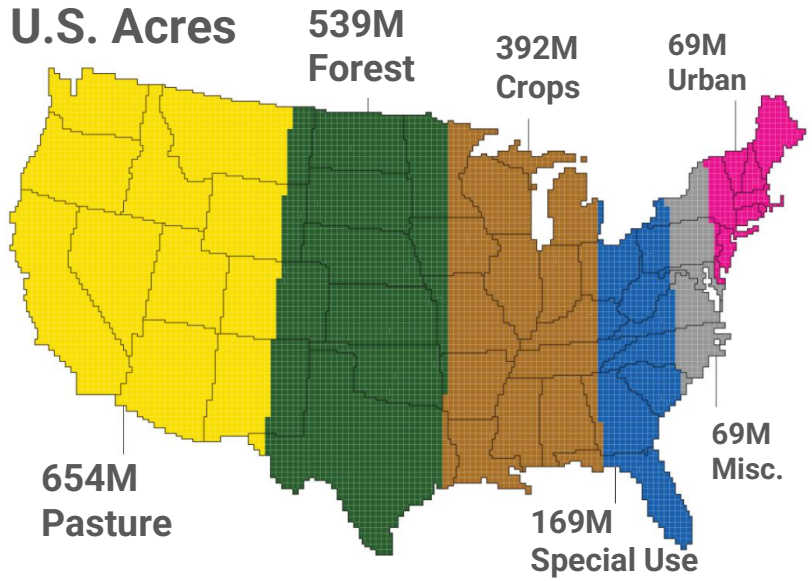
IRENA, Renewable Power Generation Costs in 2017

Fuel demands will change as ground transportation goes electric



https://www.bts.gov/data-spotlight/electric-vehicle-use-grows

Land use needs to be optimized to deliver energy, CDR, food, and ecosystem services



Today	2050*
~50M, Biofuels ~7M, Renewables	➡ +70M, E- B+ +250M, E+ RE+

*Princeton Net-Zero America
E- B+ = High Biomass
E+ RE+ High Electrification, 100% Renewable

arpa·e
CHANGING WHAT'S POSSIBLE

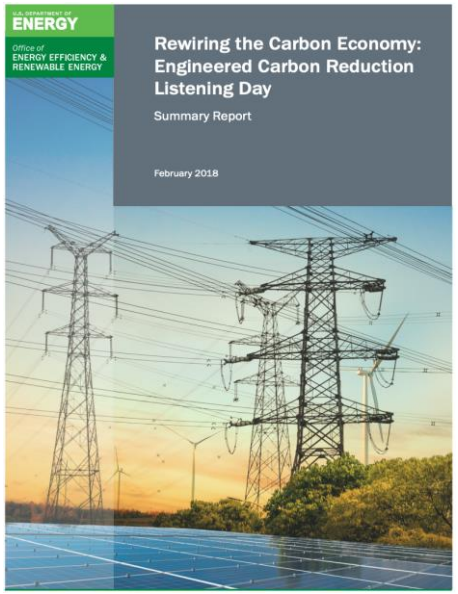
Prospect of low cost low carbon power spurs DOE *new carbon* e-fuels efforts

CO_2 Utilization Only

ARPA-E Electrofuels program launches

BETO workshops Rewiring the Carbon Economy concepts

2010 — 2017 — PRESENT



arpa·e
CHANGING WHAT'S POSSIBLE

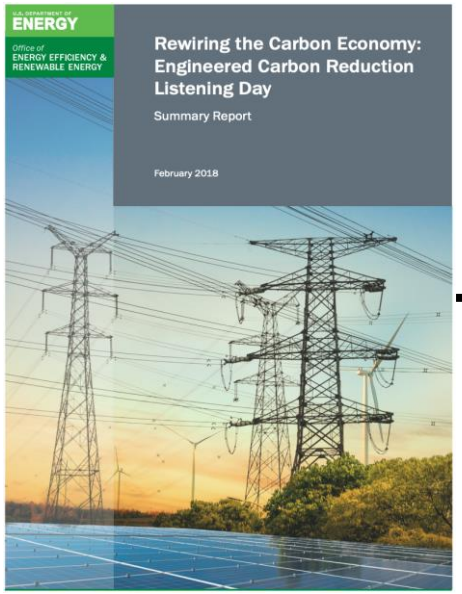
Prospect of low cost low carbon power spurs DOE *new carbon* e-fuels efforts

CO_2 Utilization Only

ARPA-E Electrofuels program launches

BETO workshops Rewiring the Carbon Economy concepts

2010 → 2017 → PRESENT



CO_2 Sourcing and Utilization

ECOSynBio

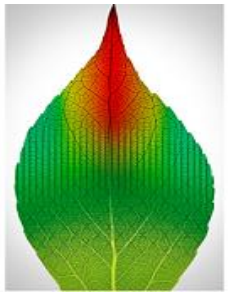
arpa·e
CHANGING WHAT'S POSSIBLE

Low cost low carbon power forces new thinking for the bioeconomy

Feedstock Production

Conversion

TERRA / ROOTS



SMARTFARM

ECOSynBio

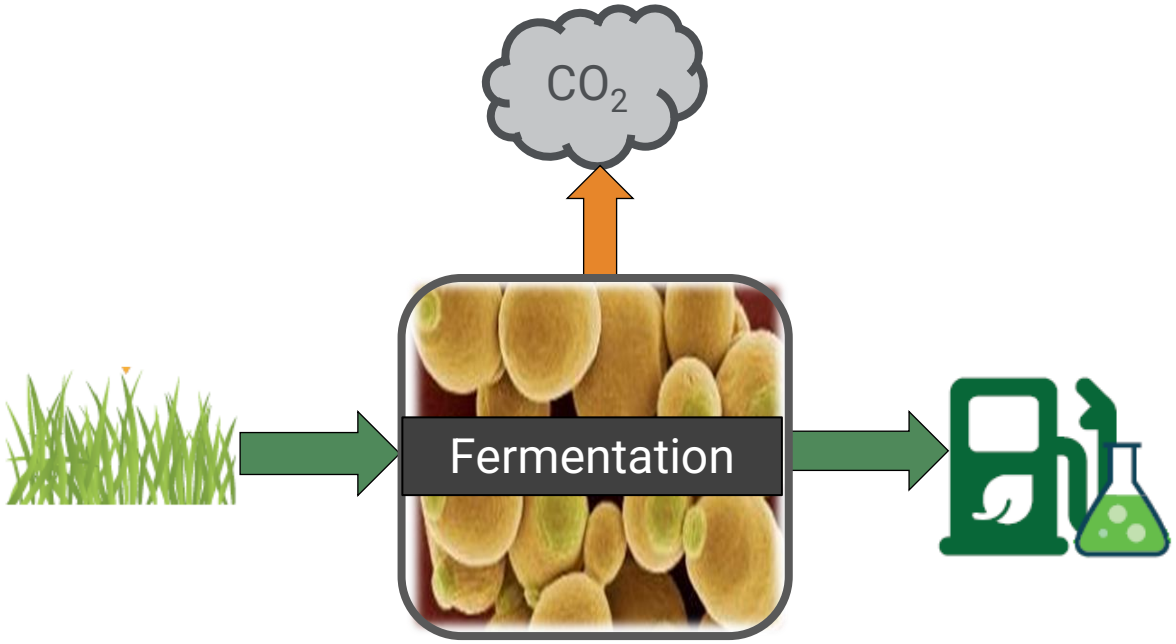
Genetics x Environment x Management x Processing

- TERRA/ROOTS
  - Identify genetics for enhanced crop characteristics, yield (TERRA) and deeper more robust roots for carbon removal and storage (ROOTS)
- SMARTFARM
  - Accurately and inexpensively measure lifecycle GHG emissions and carbon fluxes to assess the “carbon harvest” at a field level
- ECOSynBio
  - Connect the renewable energy economy with the circular carbon economy to maximize resource and carbon efficiency

arpa·e
CHANGING WHAT'S POSSIBLE

Accommodation of additional energy can drive increased C-utilization

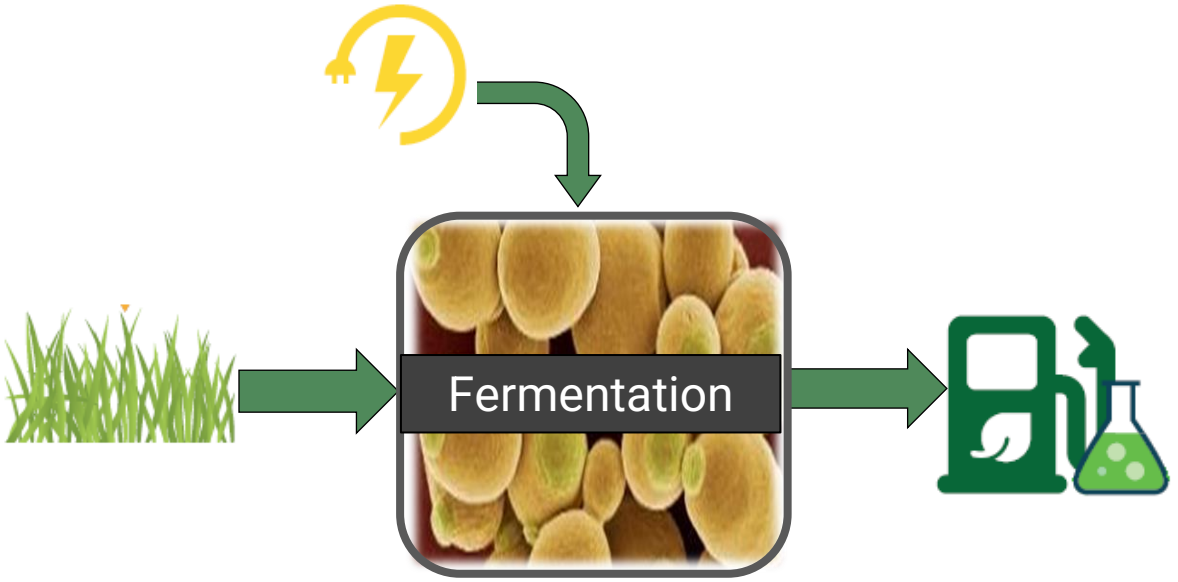
Traditional Fermentation



Sugar → Product + Carbon Dioxide

$1.5C_6H_{12}O_6 \rightarrow 3C_2H_6O + 3CO_2$

Carbon Optimized Fermentation



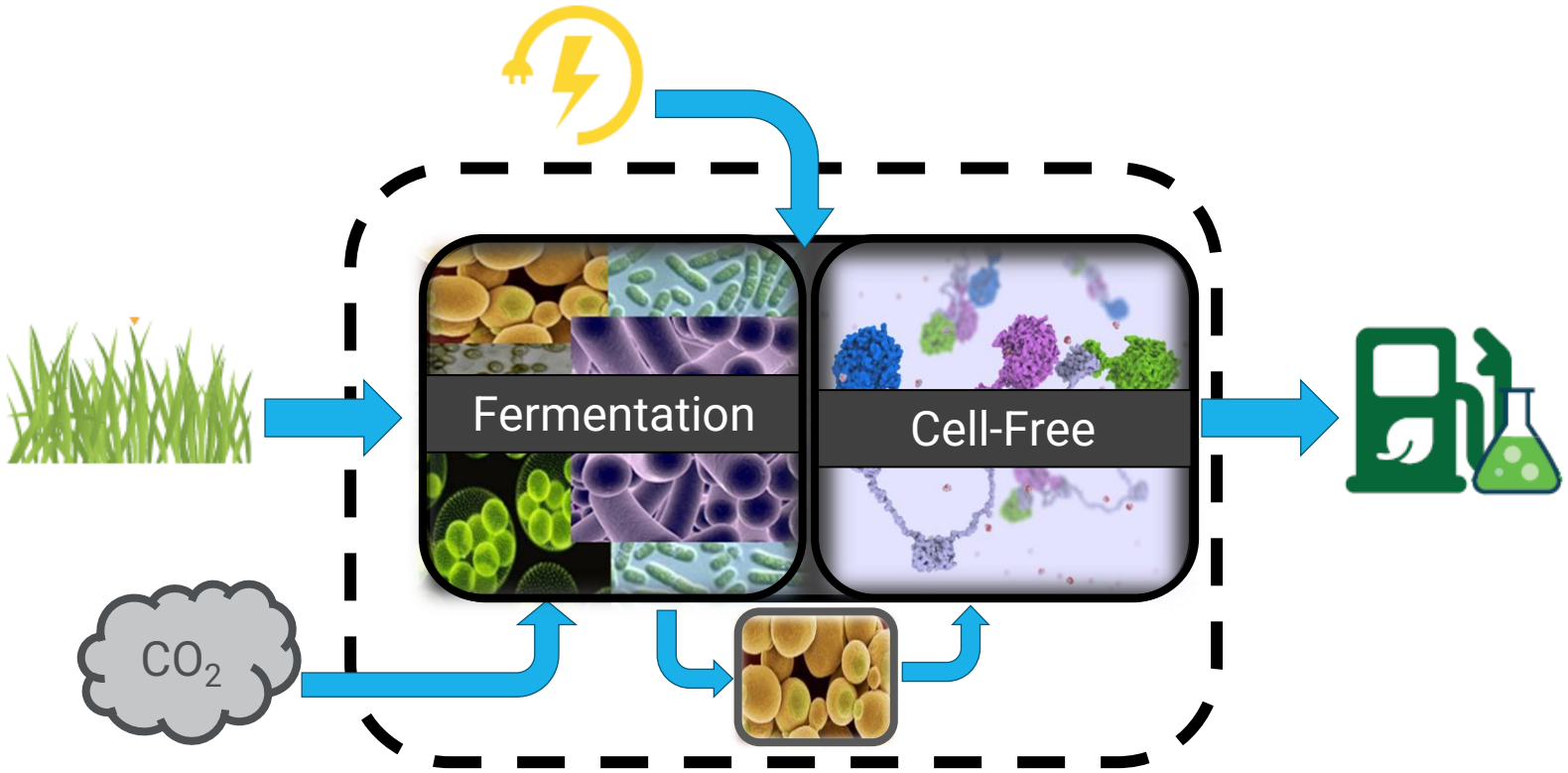
Sugar + Reducing Equivalent → Product

$C_6H_{12}O_6 + 6H_2 \rightarrow 3C_2H_6O + 3H_2O$

arpa·e
CHANGING WHAT'S POSSIBLE

ECOSynBio – Changing what's possible for biosynthesis

Carbon Optimized Bioconversion



Global metrics

- Accommodate external reducing equivalents
- Avoid CO_2 evolution
- Accumulate products with greater embodied energy than primary feedstocks

arpa·e
CHANGING WHAT'S POSSIBLE

H_2, methanol, formate, etc. and/or NADPH, ATP, etc.

Evolution of carbon sourcing and utilization

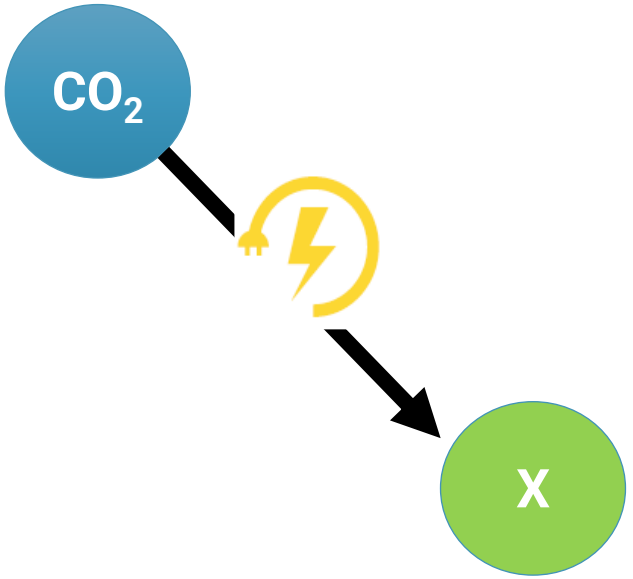
Status Quo

Carbon Sourcing and Utilization (current bioeconomy)

Current Research

Carbon Sourcing

Carbon Utilization



- To do carbon utilization concentrated carbon feedstocks are needed
- The technical capabilities to do CO_2 utilization and to do CO_2 sourcing from the air/water have proceeded at different rates and in parallel

arpa·e
CHANGING WHAT'S POSSIBLE

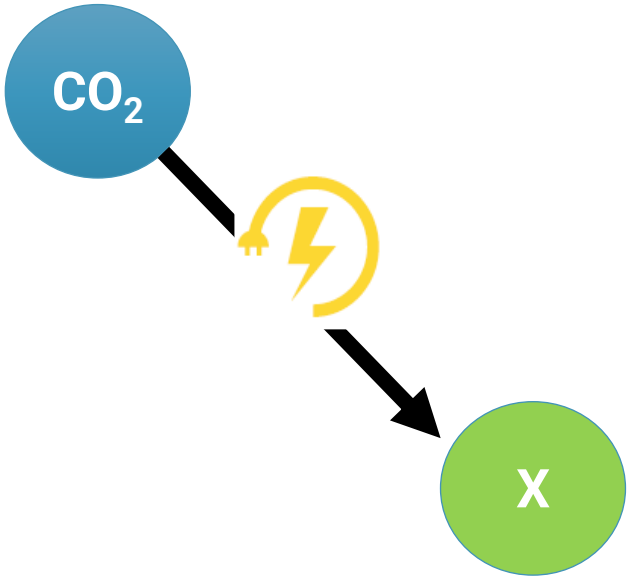
Evolution of carbon sourcing and utilization

Status Quo Capabilities and Research

Carbon Sourcing and Utilization (current bioeconomy)

Carbon Sourcing

Carbon Utilization



What's Next

Carbon Sourcing and Utilization

Electro-biofuels

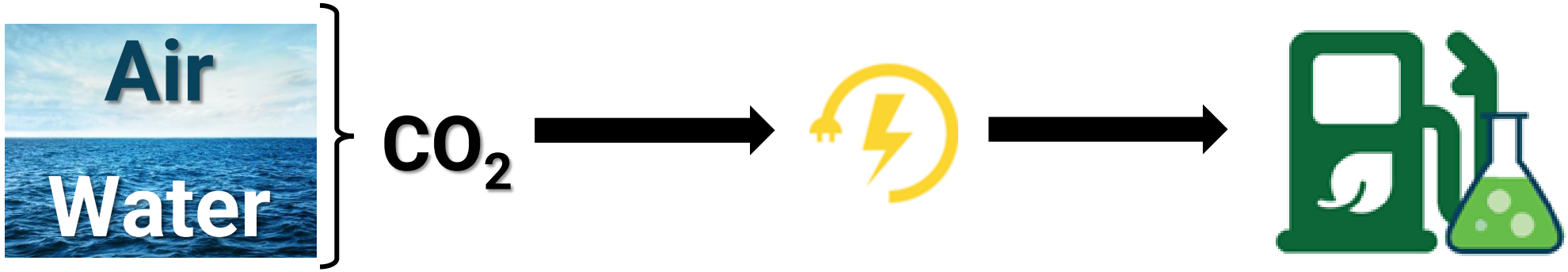
ECOSynBio

Electro-fuels

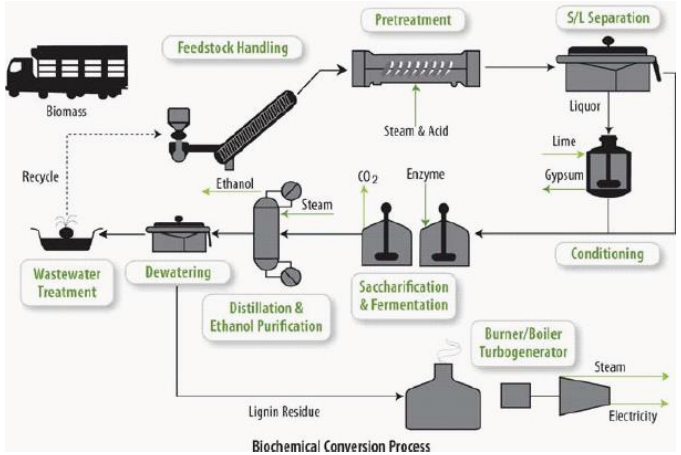
Reactive Carbon Capture and Utilization

arpa·e
CHANGING WHAT'S POSSIBLE

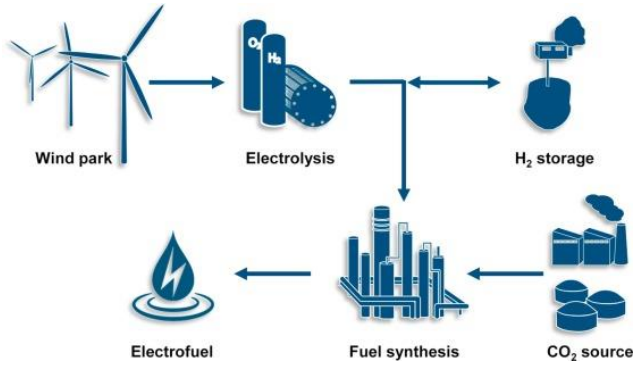
Carbon-neutral products from air or water reduce land/biomass demand



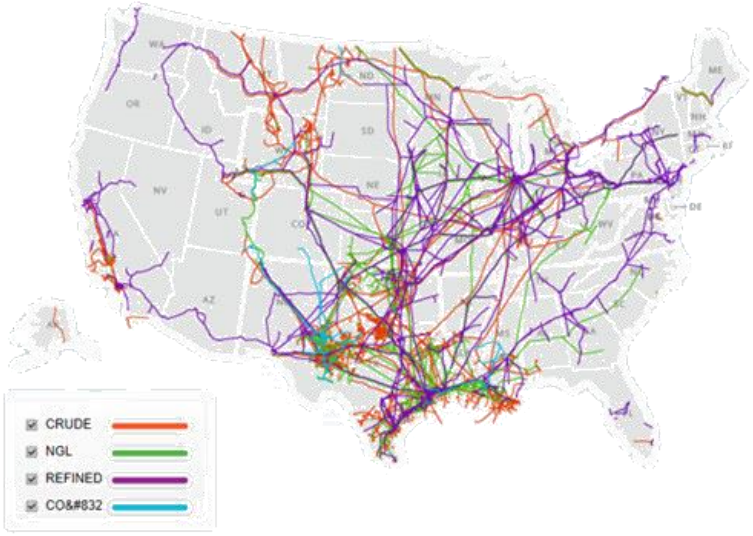
Biofuel Supply Chain



Electrofuel Supply Chain



Pipeline Infrastructure



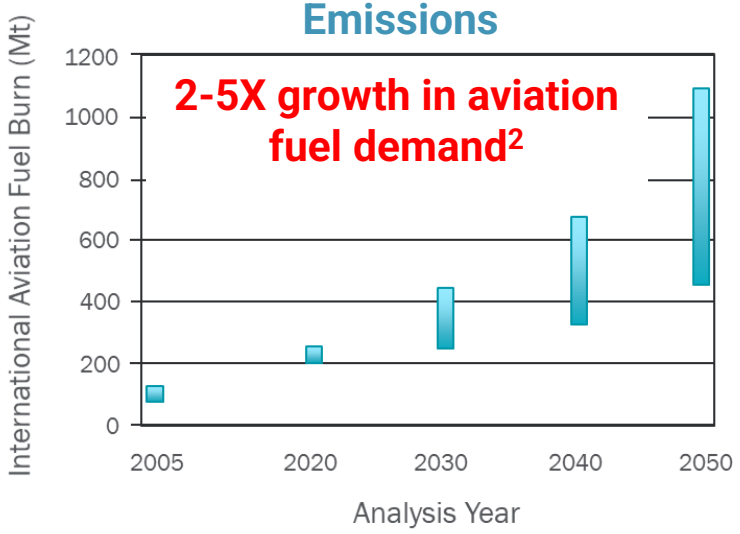
arpa·e
CHANGING WHAT'S POSSIBLE

SUMMARY AND RESEARCH NEEDS

Summary

Challenges

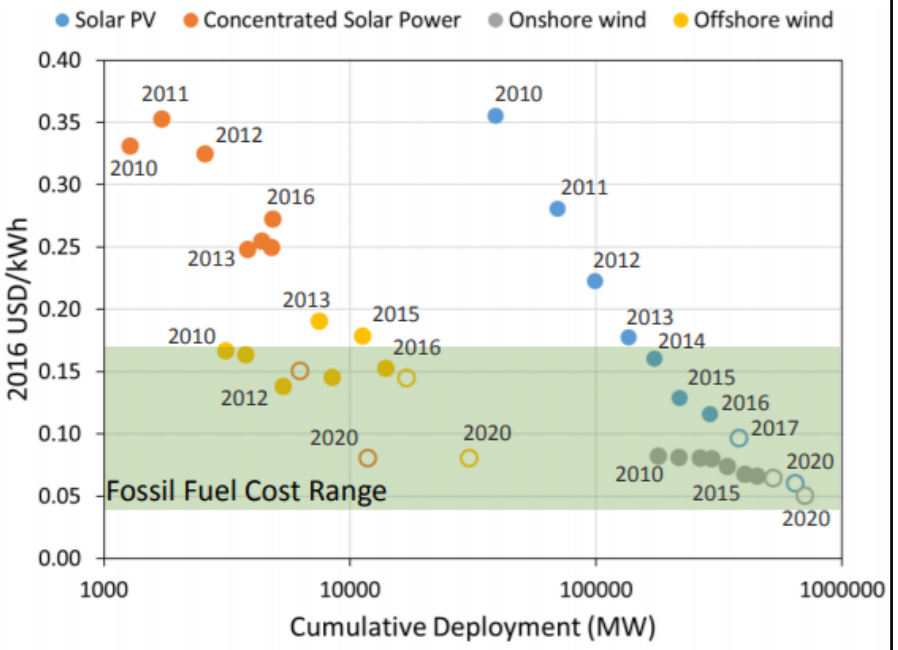
Emissions



Land

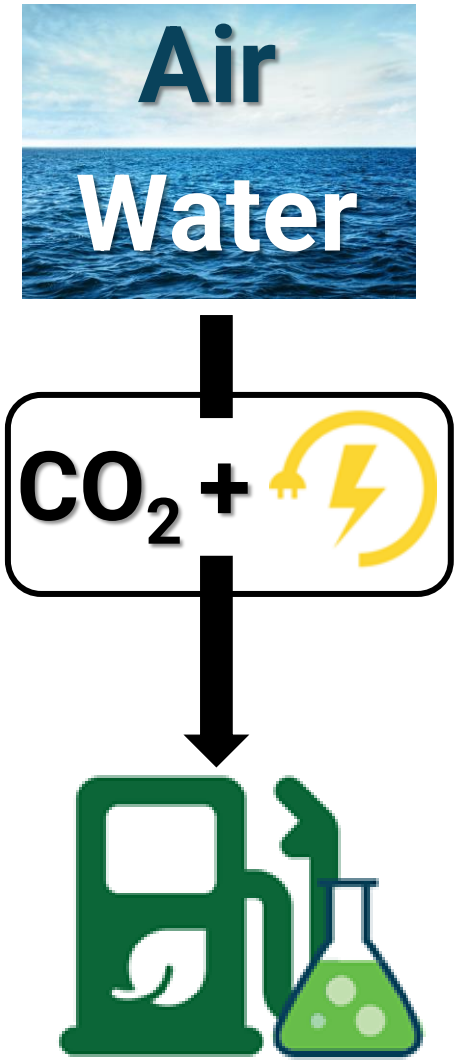
Opportunity

The cost and carbon intensity of electricity is declining[3]



Electrofuels benefit from electricity trends and can scale to cover demands that cannot be met by biofuels

Vision



Sustainable CO_2 inputs from air or water

CO_2 conversion and upgrading powered by low-cost, clean electricity

Net-Zero Carbon Fuels and Chemicals

arpa·e
CHANGING WHAT'S POSSIBLE

1. EPA GHG Inventory, 2019
2. Adapted from ICAO, 2016: Range of Uncertainties Associated with Demand Forecast, 2005 to 2050
3. IRENA, Renewable Power Generation Costs in 2017

We want you …… to help us identify *transformative* white space

- What we want
  - How do we simultaneously source carbon from the air or water and reduce it to relevant intermediates for drop in fuel synthesis?
  - What barriers exist to doing both air/water carbon sourcing and utilization in tandem?
- What we don't need
  - Discussion of new carbon utilization strategies without inherent consideration for carbon sourcing
  - Discussion of point source carbon sourcing and utilization strategies


Thank you!
David Babson, PhD | ARPA-E Program Director | David.Babson@hq.doe.gov